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THE EFFICIENCY OF A QUALITATIVE SIMURATION BY USING BDD

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Qualitative Reasoning is the analysis technique for a qualitative behavior of a system[1][8]. It is also an effective simulation method for hybrid systems under imperfect information. As an application of this research on qualitative simulation, we expect to simulate the reaction related to gene expression in system biology[9]. However, the algorithm of a qualitative simulation has to handle very large number of states in the operation to generate the reachable candidates of states, but only some the states are consistent with qualitative differential equations. Actually, the existing qualitative simulation tool, called QSIM, cannot run a simulation because of the explosive state generation when the number of states increases. To solve this problem, we try to use BDD (Binary Decision Diagram)[2][3][5], that is an effective analysis method for discrete state systems. BDD is one of efficient analysis techniques for discrete state system. BDD is useful expression method of logical functions that has advantage to treat much number of propositional variables in logical functions, compared with the truth table or the disjunctive-conjunctive normal form expression. This advantage gives significant effects to various fields. For example, in fundamental technology of VLSI design, it is important to express logical function and to apply logical operations efficiently[6]. Methods using BDD

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as a data structure of logical functions are better in memory efficiency and calculating speed. Intuitively, qualitative reasoning is an operation of searching for the state which can be reachable, by applying qualitative constraints. In other words, each reachable state is one that satisfies all constraints. We can execute an efficient qualitative simulation by using BDD. If we impliment the qualitative simulation code by useing BDD, we can check the constraints all at once. Since the reachable states have to satisfy each constraint, if we express constraints by BDD, then the operation of calculating constraints is equivalent to computing conjunction of the logical function representing candidates of stetes and the logical function representing constraints. Therefore, by implimenting the qualitative simulation by using BDD, the operation to culcurate the reachable states from the candidate of states can be done as just one operation on BDD. In this paper, we propose an effective algorithm for qualitative reasoning using BDD. By the way, qualitative reasoning using BDD calculates only a set of reachable state. We cannot know in which computation trace each state is reached from the intial state. Therefore, we use the model checking technique to check properties on traces that lead to reachable states[4]. We use CTL (Computational Tree Logic)[7][4], that is a kind of temporal logics. Temporal logic is a logical system which can treat modality. Model checking algorithm is suitable for verifying specification on finite state systems. A qualitative reasoning can be considered as a finite state machine. Therefore, we use CTL model checking algorithm for verification of the qualitative systems. In this paper, we implement a qualitative reasoning algorithm QSIM by using BDD, and compare its performance with JQSIM, an implimentation of QSIM algorithm on Java, using several examples such as bathtub models. The algorithm of JQSIM does not use BDD. Finally we have the following conclusions. In the four connected bathtub model, JQSIM runs more than 129 hours but cannot compute the reachability states. The qualitative reasoning using BDD can find all reachable states only in 0.83 sec. In the ten connected bathtub model, JQSIM cannot finish the computation but the proposing method by BDD can finish the simulations in about 20 sec. In terms of memory efficiency in the ten connected bathtub model, JQSIM explored 84004 state but it could not finish after 129 hours passed. T proposing the qualitative simulation method using

BDD outputs a BDD with 273 nodes. Even for the ten connected bath-tub model, the qualitative simulation by BDD outputs a BDD with 1743 nodes. Moreover, the proposing method can verify properties not only on states but also on traces. As a conclusion, we can say that the qualitative reasoning using BDD works effectively.

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